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United States Environmental Protection Agency

This document contains Appendices D-F from the EPA "OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)," published in November 2002. The reference number is EPA 530-D-02-004. You can find the entire document at http://www.epa.gov/epaoswer/hazwaste/ca/eis/vapor.htm.

OSWER Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater and Soils (Subsurface Vapor Intrusion Guidance)

Appendix D: Development of Tables 1, 2, and 3

Appendix E: Relevant Methods and Techniques

Appendix F: Empirical Attenuation Factors and Reliability Assessment

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APPENDIX D

DEVELOPMENT OF TABLES 1, 2, AND 3

1. Introduction

This appendix describes the data and calculations used to develop Tables 1, 2, and 3 in the guidance. Table 1 lists chemicals that may be present at hazardous waste sites and indicates whether, in our judgment, they are of sufficient toxicity and volatility to result in a potentially unacceptable indoor inhalation risk. Tables 2 and 3 provide generally recommended target concentrations for contaminants in indoor air, groundwater, and soil gas. For non-carcinogens, these values are based on the appropriate reference concentration, and for carcinogens, they are calculated using a method consistent with the approach in EPA's *Supplemental Guidance for Developing Soil Screening Levels* (EPA, to be published). Only chemicals that are, in our judgment, sufficiently volatile and toxic to pose an inhalation risk are included in Tables 2 and 3. The approach described here also can be used, as appropriate, to evaluate chemicals not listed in the tables.

2. Description of Tables 1, 2 and 3

Table 1 lists the chemicals that may be found at hazardous waste sites and indicates whether, in our judgment, they are sufficiently toxic and volatile to result in a potentially unacceptable indoor inhalation risk. It also provides a column for checking off the chemicals found or reasonably suspected to be present in the subsurface at a site. Under this approach, a chemical is considered sufficiently toxic if the vapor concentration of the pure component (see Section 4 below) poses an incremental lifetime cancer risk greater than 10^{-6} or results in a non-cancer hazard index greater than one (see Section 5 below). A chemical is considered sufficiently volatile if its Henry's Law Constant is 1×10^{-5} atm-m^3/mol or greater (US EPA, 1991). In our judgement, if a chemical does not meet both of these criteria, it need not be further considered as part of the evaluation.

Table 2 provides generic soil gas and groundwater screening concentrations corresponding to risk-based concentrations for indoor air in residential settings calculated using the methodology described in Section 5 below. Blank columns are included to allow the user to enter measured or reasonably estimated concentrations specific to a site. The target soil gas and groundwater concentrations are calculated using generic vapor intrusion attenuation factors (see Appendix F) as described in Sections 6 and 7 below.

Table 3 provides soil gas and groundwater screening concentrations for a select set of attenuation factors. Guidance for selecting the appropriate attenuation factor to use is given in Question 5. As with Table 2, the target soil gas and groundwater concentrations are calculated using the approach described in Sections 6 and 7 below and correspond to risk-based concentrations for indoor air in residential settings calculated using the methodology described in Section 5 below.

The target concentrations in Tables 2 and 3 are screening levels. They are not intended to be used as clean-up levels nor are they intended to supercede existing criteria of the lead regulatory authority. The lead regulatory authority for a site may determine that criteria other than those provided herein are appropriate for the specific site or area. Thus, we recommend that the user's initial first step should involve consultation with their lead regulatory authority to identify the most appropriate criteria to use.

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3. Data Sources

Chemical Property Data - The source of chemical data used to calculate the values in Tables 1, 2, and 3 is primarily EPA's Superfund Chemical Data Matrix (SCDM) database. EPA's WATER9 database was used for chemicals not included in the SCDM database.

Toxicity Values - EPA's Integrated Risk Information System (IRIS) is the generally preferred source of carcinogenic unit risks and non-carcinogenic reference concentrations (RfCs) for inhalation exposure.[1] The following two sources were consulted, in order of preference, when IRIS values were not available: provisional toxicity values recommended by EPA's National Center for Environmental Assessment (NCEA) and EPA's Health Effects Assessment Summary Tables (HEAST). If no inhalation toxicity data could be obtained from IRIS, NCEA, or HEAST, we derived extrapolated unit risks and/or RfCs using toxicity data for oral exposure (cancer slope factors and/or reference doses, respectively) from these same sources utilizing the same preference order.[2] Target concentrations that were calculated using these extrapolated toxicity values are clearly indicated in Tables 2 and 3. Note that for most compounds, extrapolation from oral data introduces considerable uncertainty into the resulting inhalation value. Values obtained from inhalation studies or from pharmacokinetic modeling applied to oral doses will be less uncertain than those calculated using the equations below.

EPA's Integrated Risk Information System (IRIS) currently does not include carcinogenicity data for TCE, a volatile contaminant frequently encountered at hazardous waste sites. The original carcinogenicity assessment for TCE, which was based on a health risk assessment conducted in the late 1980's, was withdrawn from IRIS in 1994. The Superfund Technical Support Center has continued to recommend use of the cancer slope factor from the withdrawn assessment, until a reassessment of the carcinogenicity of TCE is completed. In 2001, the Agency published a draft of the TCE toxicity assessment for public comment.[3] In this guidance, we have calculated TCE target concentrations using a cancer slope factor identified in that document, which is available on the National Center for Environmental Assessment (NCEA) web site. We selected this slope factor because it is based on state-of-the-art methodology. However, because this document is still undergoing review, the slope factor and the target concentrations calculated for TCE are subject to change and should be considered "provisional" values.

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[1]U.S. EPA. 2002. Integrated Risk Information System (IRIS). http://www.epa.gov/iriswebp/iris/index.html. November.

[2]The oral-to-inhalation extrapolations assume an adult inhalation rate (IR) of 20 m^3/day and an adult body weight (BW) of 70 kg. Unit risks (URs) were extrapolated from cancer slope factors (CSFs) using the following equation:

$$UR\ (:g/m^3)^{-1} = CSF\ (mg/kg/d)^{-1} * IR\ (m^3/d) * (1/BW)\ (kg^{-1}) * (10^{-3}\ mg/:g)$$

Reference concentrations (RfCs) were extrapolated from reference doses (RfDs) using the following equation:

$$RfC\ (mg/m^3) = RfD\ (mg/kg/d) * (1/IR)\ (m3/d)^{-1} * BW\ (kg)$$

[3]US EPA, Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft, Office of Research and Development, EPA/600/P-01/002A, August, 2001.

Table D-1 summarizes the toxicity values used in this guidance document, along with their sources. The table also indicates which unit risks and RfCs have been extrapolated from oral toxicity values and whether the indoor air target concentration is based on an oral extrapolated toxicity value. Please note that toxicity databases such as IRIS are routinely updated as new information becomes available; this table is current as of November 2002. Users of this guidance are strongly encouraged to research the latest toxicity values for contaminants of interest from the sources noted above. In the next year, IRIS reassessments are expected for several contaminants commonly found in subsurface contamination whose inhalation toxicity values today are based upon extrapolation.

4. Maximum Pure Component Vapor Concentration

The maximum possible vapor concentration is that corresponding to the pure chemical at the temperature of interest. In this case, all calculations were performed at the reference temperature of 25C using the equation:

$C_{max,vp} = S * H * 10^3 : g/mg * 10^3 L/m^3$

where

$C_{max,vp}$ = maximum pure component vapor concentration at 25C [$: g/m^3$],
S = pure component solubility at 25C [mg/L], and
H = dimensionless Henry's Law Constant at 25C [(mg/L – vapor)/(mg/L – H_2O)].

To determine if a chemical is sufficiently toxic to potentially pose an unacceptable inhalation risk, the calculated pure component vapor concentrations were compared to target indoor air concentrations corresponding to an incremental lifetime cancer risk greater than 10^{-6} or a non-cancer hazard index greater than one.

5. Target Indoor Air Concentration to Satisfy Both the Prescribed Cancer Risk Level and the Target Hazard Index.

The target breathing zone indoor air concentrations in Tables 1, 2, and 3 are risk-based screening levels for ambient air. The indoor air concentrations for non-carcinogens are set at the appropriate reference concentration, and the concentrations for carcinogens are calculated following an approach consistent with EPA's *Supplemental Guidance for Developing Soil Screening Levels* (EPA, to be published). The toxicity values on which the calculations are based are listed in Table D-1, which also shows the source of the toxicity data. Separate carcinogenic and non-carcinogenic target concentrations were calculated for each compound when both unit risks and reference concentrations were available. When inhalation toxicity values were not available, unit risks and/or reference concentrations were extrapolated from oral slope factors and/or reference doses, respectively. For carcinogens, target indoor air concentrations were based on an adult residential exposure scenario and assume exposure of an individual for 350 days per year over a period of 30 years. For non-carcinogens, target indoor air concentrations are set at the corresponding reference concentration. An inhalation rate of 20 m^3/day and a body weight of 70 kg are assumed and have been factored into the inhalation unit risk and reference concentration toxicity values.

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For carcinogens,

C_{cancer} ($\mu g/m^3$) = [(TCR * AT_c)/(EF * ED * URF)]

For non-carcinogens,

$C_{non\text{-}cancer}$ ($\mu g/m^3$) = (THQ * RfC * 1000 $\mu g/mg$)

where

C_{cancer} = target indoor air concentration, carcinogen, ($\mu g/m^3$)
$C_{non\text{-}cancer}$ = target indoor air concentration, non-carcinogen, ($\mu g/m^3$)
TCR = target cancer risk (*e.g.*, 1.0 x 10^{-5})
THQ = target hazard quotient (*e.g.*, 1.0)
URF = unit risk factor ($\mu g/m^3$)$^{-1}$
RfC = reference concentration (mg/m^3)
AT_c = averaging time, carcinogens (25,550 days)
EF = exposure frequency (350 days/year)
ED = exposure duration (30 years)

For most compounds, the more stringent of the cancer- and non-cancer-based contaminant concentrations is chosen as the target indoor air concentration that satisfies both the prescribed cancer risk level and the target hazard quotient.

$C_{target,ia}$ = MIN(C_{cancer}, $C_{non\text{-}cancer}$)

However, we generally prefer to base the target concentration on non-extrapolated toxicity values wherever possible. Therefore, for compounds with one inhalation-based toxicity value and one oral-extrapolated value, the screening level based on the non-extrapolated toxicity value is chosen as the target indoor air concentration.[4]

For ease in application of the tables, the indoor air concentrations are given in units of $\mu g/m^3$ as well as ppbv. The conversion from ppbv to $\mu g/m^3$ is:

C [ppbv] = C [$\mu g/m^3$] * 10^9 [ppb/atm] * 10^{-3} [m^3/L] * R * T/(MW * 10^6 [$\mu g/g$])

where

[4] The target indoor air concentration for trichloroethylene is the lone exception. The target concentration is based on a carcinogenic unit risk extrapolated from an upper bound oral cancer slope factor of $4x10^{-1}$ per mg/kg/d cited in NCEA's draft risk assessment for trichloroethylene (US EPA, 2001). However, as noted in that document, available evidence from toxicological studies suggests similar carcinogenic effects from both the oral and inhalation routes of exposure. The existence of this evidence gives greater weight to the extrapolated unit risk, and given that the unit risk produces a lower target concentration than the non-extrapolated RfC, we used the unit risk-based value as the target indoor air concentration for trichloroethylene. (As noted earlier, the trichloroethylene risk assessment is still under review. As a result, the cancer slope factor and extrapolated unit risk values for trichloroethylene are subject to change.)

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R = gas constant (0.0821 L-atm/mole-K),
T = absolute temperature (298 K), and
MW = molecular weight (g/mole).

The calculated target indoor air concentrations are listed in Tables 2 and 3 along with a column indicating whether cancer or non-cancer risks drive the target concentration. A separate column indicates whether risks are calculated using provisional, oral-extrapolated toxicity values (i.e., inhalation values extrapolated from oral CSFs or RfDs) (see Table D-1).

6. Target Soil Gas Concentration Corresponding to Target Indoor Air Concentration

The target soil gas concentration corresponding to a chemical's target indoor air concentration was calculated by dividing the indoor air concentration by an appropriate attenuation factor (see Questions 4 and 5 in the guidance and Appendix F). The attenuation factor represents the factor by which subsurface vapor concentrations migrating into indoor air spaces are reduced due to diffusive, advective, and/or other attenuating mechanisms. The attenuation factor can be empirically determined or calculated using an appropriate vapor intrusion model. Once the appropriate attenuation factor was determined, the target soil concentration was calculated as:

$C_{soil\text{-}gas}$ [: g/m^3] = $C_{target,ia}$ [: g/m^3] / α

or

$C_{soil\text{-}gas}$ [ppbv] = $C_{target,ia}$ [ppbv] / α

where

$C_{soil\text{-}gas}$ = target soil gas concentration [: g/m3] and
α = attenuation factor (ratio of indoor air concentration to source vapor concentration)

If $C_{target,ia}$ exceeds the maximum possible pure chemical vapor concentration, the designation "*" is entered in the table. If $C_{soil\text{-}gas}$ exceeds the maximum possible pure chemical vapor concentration at 25C, but $C_{target,ia}$ does not, then "**" is entered in the table.

7. Target Groundwater Concentration Corresponding to Target Indoor Air Concentration

The target groundwater concentration corresponding to a chemical's target indoor air concentration is calculated by dividing the target indoor air concentration by an appropriate attenuation factor (see Questions 4 and 5 in the guidance and Appendix F) and then converting the vapor concentration to an equivalent groundwater concentration assuming equilibrium between the aqueous and vapor phases at the water table. Diffusion resistances across the capillary fringe are assumed to be accounted for in the value of α. The equilibrium partitioning is assumed to obey Henry's Law so that:

C_{gw} [: g/L] = $C_{target,ia}$ [: g/m^3] * 10^{-3} m^3/L * 1/H *1/α

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where

C_{gw} = target groundwater concentration,
α = attenuation factor (ratio of indoor air concentration to source vapor concentration).
H = dimensionless Henry's Law Constant at 25C [(mg/L – vapor)/(mg/L – H_2O)].

If $C_{target,ia}$ exceeds the maximum possible pure chemical vapor concentration, the designation "*" is entered in the table. If C_{gw} exceeds the aqueous solubility of the pure chemical, but $C_{target,ia}$ does not, then "**" is entered in the table

If the calculated groundwater target concentration is less than the Maximum Contaminant Level (MCL) for the compound, the target concentration is set at the MCL. Target concentrations set at the MCL are indicated in Tables 2 and 3 by this symbol ("†").

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8. References

US EPA, 1991, Risk Assessment Guidance for Superfund: Volume 1 – Human Health Evaluation Manual, Part B.

IRIS - Integrated Risk Information System - US EPA Office of Research and Development - National Center for Environmental Assessment. [http://www.epa.gov/iriswebp/iris/index.html] November 2002.

US EPA, Supplemental Guidance for Developing Soil Screening Levels, Office of Emergency and Remedial Response, OSWER 9355.4-24 (EPA, to be published).

US EPA, Trichloroethylene Health Risk Assessment: Synthesis and Characterization - External Review Draft, Office of Research and Development, EPA/600/P-01/002A, August 2001.

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Table D-1

Toxicological Values Used to Calculate Target Concentrations in Indoor Air, Soil Gas, and Groundwater

CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
83329	Acenaphthene	NA	NA		2.1E-01	I	yes	yes
75070	Acetaldehyde	2.2E-06	I	no	9.0E-03	I	no	no
67641	Acetone	NA	NA		3.5E-01	I	yes	yes
75058	Acetonitrile	NA	NA		6.0E-02	I	no	no
98862	Acetophenone	NA	NA		3.5E-01	I	yes	yes
107028	Acrolein	NA	NA		2.0E-05	I	no	no
107131	Acrylonitrile	6.8E-05	I	no	2.0E-03	I	no	no
309002	Aldrin	4.9E-03	I	no	1.1E-04	I	yes	no
319846	alpha-HCH (alpha-BHC)	1.8E-03	I	no	NA	NA		no
62533	Aniline	1.6E-06	I		1.0E-03	I	no	no
120127	Anthracene	NA	NA		1.1E+00	I	yes	yes
56553	Benz(a)anthracene	2.1E-04	E	yes	NA	NA		yes
100527	Benzaldehyde	NA	NA		3.5E-01	I	yes	yes
71432	Benzene	7.8E-06	I	no	NA	NA		no
50328	Benzo(a)pyrene	1.5E-01	I	yes	NA	NA		yes
205992	Benzo(b)fluoranthene	2.1E-04	E	yes	NA	NA		yes
207089	Benzo(k)fluoranthene	2.1E-05	E	yes	NA	NA		yes
65850	Benzoic Acid	NA	NA		1.4E+01	I	yes	yes
100516	Benzyl alcohol	NA	NA		1.1E+00	H	yes	yes
100447	Benzylchloride	4.9E-05	I	yes	NA	NA		yes

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91587	beta-Chloronaphthalene	NA	NA		2.8E-01	I	yes	yes
319857	beta-HCH (beta-BHC)	5.3E-04	I	no	NA	NA		no
92524	Biphenyl	NA	NA		1.8E-01	I	yes	yes
111444	Bis(2-chloroethyl)ether	3.3E-04	I	no	NA	NA		no
108601	Bis(2-chloroisopropyl)ether	1.0E-05	H	no	1.4E-01	I	yes	no
117817	Bis(2-ethylhexyl)phthalate	NA	NA		7.0E-02	I	yes	yes
542881	Bis(chloromethyl)ether	6.2E-02	I	no	NA	NA		no
75274	Bromodichloromethane	1.8E-05	I	yes	7.0E-02	I	yes	yes
75252	Bromoform	1.1E-06	I	no	7.0E-02	I	yes	no
106990	1,3-Butadiene	2.8E-04	I	no	NA	NA		no
71363	Butanol	NA	NA		3.5E-01	I	yes	yes
85687	Butyl benzyl phthalate	NA	NA		7.0E-01	I	yes	yes
86748	Carbazole	5.7E-06	H	yes	NA	NA		yes
75150	Carbon disulfide	NA	NA		7.0E-01	I	no	no
56235	Carbon tetrachloride	1.5E-05	I	no	NA	NA		no
57749	Chlordane	1.0E-04	I	no	7.0E-04	I	no	no
126998	2-Chloro-1,3-butadiene (chloroprene)	NA	NA		7.0E-03	H	no	no
108907	Chlorobenzene	NA	NA		6.0E-02	E	no	no
109693	1-Chlorobutane	NA	NA		1.4E+00	H	yes	yes

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124481	Chlorodibromomethane	2.4E-05	I	yes	7.0E-02	I	yes	yes
75456	Chlorodifluoromethane	NA	NA		5.0E+01	I	no	no
75003	Chloroethane (ethyl chloride)	8.3E-07	E	yes	1.0E+01	I	no	no
67663	Chloroform	2.3E-05	I	no	NA	NA		no
95578	2-Chlorophenol	NA	NA		1.8E-02	I	yes	yes
75296	2-Chloropropane	NA	NA		1.0E-01	H	no	no
218019	Chrysene	2.1E-06	E	yes	NA	NA		yes
156592	cis-1,2-Dichloroethylene	NA	NA		3.5E-02	H	yes	yes
123739	Crotonaldehyde (2-butenal)	5.4E-04	H	yes	NA	NA		yes
98828	Cumene	NA	NA		4.0E-01	I	no	no
72548	DDD	6.9E-05	I	yes	NA	NA		yes
72559	DDE	9.7E-05	I	yes	NA	NA		yes
50293	DDT	9.7E-05	I	no	1.8E-03	I	yes	no
53703	Dibenz(a,h)anthracene	2.1E-03	E	yes	NA	NA		yes
132649	Dibenzofuran	NA	NA		1.4E-02	E	yes	yes
96128	1,2-Dibromo-3-chloropropane	6.9E-07	H	no	2.0E-04	I	no	no
106934	1,2-Dibromoethane (ethylene dibromide)	2.2E-04	I	no	2.0E-04	H	no	no
541731	1,3-Dichlorobenzene	NA	NA		1.1E-01	E	yes	yes
95501	1,2-Dichlorobenzene	NA	NA		2.0E-01	H	no	no

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106467	1,4-Dichlorobenzene	NA	NA		8.0E-01	I	no	no
91941	3,3-Dichlorobenzidine	1.3E-04	I	yes	NA	NA		yes
75718	Dichlorodifluoromethane	NA	NA		2.0E-01	H	no	no
75343	1,1-Dichloroethane	NA	NA		5.0E-01	H	no	no
107062	1,2-Dichloroethane	2.6E-05	I	no	NA	NA		no
75354	1,1-Dichloroethylene	NA	NA		2.0E-01	E	no	no
120832	2,4-Dichlorophenol	NA	NA		1.1E-02	I	yes	yes
78875	1,2-Dichloropropane	1.9E-05	H	yes	4.0E-03	I	no	no
542756	1,3-Dichloropropene	4.0E-06	I	no	2.0E-02	I	no	no
60571	Dieldrin	4.6E-03	I	no	1.8E-04	I	yes	no
84662	Diethylphthalate	NA	NA		2.8E+00	I	yes	yes
105679	2,4-Dimethylphenol	NA	NA		7.0E-02	I	yes	yes
131113	Dimethylphthalate	NA	NA		NA	NA		
84742	Di-n-butyl phthalate	NA	NA		3.5E-01	I	yes	yes
534521	4,6-Dinitro-2-methylphenol (4,6-dinitro-o-cresol)	NA	NA		3.5E-03	E	yes	yes
51285	2,4-Dinitrophenol	NA	NA		7.0E-03	I	yes	yes
121142	2,4-Dinitrotoluene	1.9E-04	I	yes	7.0E-03	I	yes	yes
606202	2,6-Dinitrotoluene	1.9E-04	I	yes	3.5E-03	H	yes	yes

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CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
117840	Di-n-octyl phthalate	NA	NA		7.0E-02	H	yes	yes
115297	Endosulfan	NA	NA		2.1E-02	I	yes	yes
72208	Endrin	NA	NA		1.1E-03	I	yes	yes
106898	Epichlorohydrin	1.2E-06	I	no	1.0E-03	I	no	no
60297	Ethyl ether	NA	NA		7.0E-01	I	yes	yes
141786	Ethylacetate	NA	NA		3.2E+00	I	yes	yes
100414	Ethylbenzene	1.1E-06	E	no	1.0E+00	I	no	no
75218	Ethylene oxide	1.0E-04	H	no	NA	NA		no
97632	Ethylmethacrylate	NA	NA		3.2E-01	H	yes	yes
206440	Fluoranthene	NA	NA		1.4E-01	I	yes	yes
86737	Fluorene	NA	NA		1.4E-01	I	yes	yes
110009	Furan	NA	NA		3.5E-03	I	yes	yes
58899	gamma-HCH (Lindane)	3.7E-04	H	yes	1.1E-03	I	yes	yes
76448	Heptachlor	1.3E-03	I	no	1.8E-03	I	yes	no
1024573	Heptachlor epoxide	2.6E-03	I	no	4.6E-05	I	yes	no
87683	Hexachloro-1,3-butadiene	2.2E-05	I	no	7.0E-04	H	yes	no
118741	Hexachlorobenzene	4.6E-04	I	no	2.8E-03	I	yes	no
77474	Hexachlorocyclopentadiene	NA	NA		2.0E-04	I	no	no
67721	Hexachloroethane	4.0E-06	I	no	3.5E-03	I	yes	no

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CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
110543	Hexane	NA	NA		2.0E-01	I	no	no
74908	Hydrogen cyanide	NA	NA		3.0E-03	I	no	no
193395	Indeno(1,2,3-cd)pyrene	2.1E-04	E	yes	NA	NA		yes
78831	Isobutanol	NA	NA		1.1E+00	I	yes	yes
78591	Isophorone	2.7E-07	I	yes	7.0E-01	I	yes	yes
7439976	Mercury (elemental)	NA	NA		3.0E-04	I	no	no
126987	Methacrylonitrile	NA	NA		7.0E-04	A	no	no
72435	Methoxychlor	NA	NA		1.8E-02	I	yes	yes
79209	Methyl acetate	NA	NA		3.5E+00	H	yes	yes
96333	Methyl acrylate	NA	NA		1.1E-01	A	yes	yes
74839	Methyl bromide	NA	NA		5.0E-03	I	no	no
74873	Methyl chloride (chloromethane)	1.0E-06	E	no	9.0E-02	I	no	no
108872	Methylcyclohexane	NA	NA		3.0E+00	H	no	no
74953	Methylene bromide	NA	NA		3.5E-02	A	yes	yes
75092	Methylene chloride	4.7E-07	I	no	3.0E+00	H	no	no
78933	Methylethylketone (2-butanone)	NA	NA		1.0E+00	I	no	no
108101	Methylisobutylketone (4-methyl-2-pentanone)	NA	NA		8.0E-02	H	no	no
80626	Methylmethacrylate	NA	NA		7.0E-01	I	no	no

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Table D-1

Toxicological Values Used to Calculate Target Concentrations in Indoor Air, Soil Gas, and Groundwater

CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
91576	2-Methylnaphthalene	NA	NA		7.0E-02	E	yes	yes
108394	3-Methylphenol (m-cresol)	NA	NA		1.8E-01	I	yes	yes
95487	2-Methylphenol (o-cresol)	NA	NA		1.8E-01	I	yes	yes
106455	4-Methylphenol (p-cresol)	NA	NA		1.8E-02	H	yes	yes
99081	m-Nitrotoluene	NA	NA		7.0E-02	E	yes	yes
1634044	MTBE	NA	NA		3.0E+00	I	no	no
108383	m-Xylene	NA	NA		7.0E+00	H	yes	yes
91203	Naphthalene	NA	NA		3.0E-03	I	no	no
104518	n-Butylbenzene	NA	NA		1.4E-01	E	yes	yes
98953	Nitrobenzene	NA	NA		2.0E-03	H	no	no
100027	4-Nitrophenol	NA	NA		2.8E-02	E	yes	yes
79469	2-Nitropropane	2.7E-03	H	no	2.0E-02	I	no	no
924163	N-Nitroso-di-n-butylamine	1.6E-03	I	no	NA	NA		no
621647	N-Nitrosodi-n-propylamine	2.0E-03	I	yes	NA	NA		yes
86306	N-Nitrosodiphenylamine	1.4E-06	I	yes	NA	NA		yes
103651	n-Propylbenzene	NA	NA		1.4E-01	E	yes	yes
88722	o-Nitrotoluene	NA	NA		3.5E-02	H	yes	yes
95476	o-Xylene	NA	NA		7.0E+00	H	yes	yes
106478	p-Chloroaniline	NA	NA		1.4E-02	I	yes	yes

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Table D-1

Toxicological Values Used to Calculate Target Concentrations in Indoor Air, Soil Gas, and Groundwater

CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
87865	Pentachlorophenol	3.4E-05	I	yes	1.1E-01	I	yes	yes
108952	Phenol	NA	NA		2.1E+00	I	yes	yes
99990	p-Nitrotoluene	NA	NA		3.5E-02	H	yes	yes
106423	p-Xylene	NA	NA		7.0E+00	I	yes	yes
129000	Pyrene	NA	NA		1.1E-01	I	yes	yes
110861	Pyridine	NA	NA		3.5E-03	I	yes	yes
135988	sec-Butylbenzene	NA	NA		1.4E-01	E	yes	yes
100425	Styrene	NA	NA		1.0E+00	I	no	no
98066	tert-Butylbenzene	NA	NA		1.4E-01	E	yes	yes
630206	1,1,1,2-Tetrachloroethane	7.4E-06	I	no	1.1E-01	I	yes	no
79345	1,1,2,2-Tetrachloroethane	5.8E-05	I	no	2.1E-01	E	yes	no
127184	Tetrachloroethylene	3.0E-06	E	no	NA	NA		no
108883	Toluene	NA	NA		4.0E-01	I	no	no
8001352	Toxaphene	3.2E-04	I	no	NA	NA		no
156605	trans-1,2-Dichloroethylene	NA	NA		7.0E-02	I	yes	yes
76131	1,1,2-Trichloro-1,2,2-trifluoroethane	NA	NA		3.0E+01	H	no	no
120821	1,2,4-Trichlorobenzene	NA	NA		2.0E-01	H	no	no
79005	1,1,2-Trichloroethane	1.6E-05	I	no	1.4E-02	I	yes	no
71556	1,1,1-Trichloroethane	NA	NA		2.2E+00	E	no	no

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Table D-1

Toxicological Values Used to Calculate Target Concentrations in Indoor Air, Soil Gas, and Groundwater

CASN	Chemical	Unit Risk Factor (URF) (: $g/m^3)^{-1}$	URF Source	Is URF Extrapolated From Oral Value?	Reference Concentration (RfC) (mg/m^3)	RfC Source	Is RfC Extrapolated From Oral Value?	Is Indoor Air Target Concentration Based on Extrapolated Value?
79016	Trichloroethylene *	1.1E-04	E	yes	4.0E-02	E	no	yes
75694	Trichlorofluoromethane	NA	NA		7.0E-01	A	no	no
95954	2,4,5-Trichlorophenol	NA	NA		3.5E-01	I	yes	yes
88062	2,4,6-Trichlorophenol	3.1E-06	I	no	NA	NA		no
96184	1,2,3-Trichloropropane	5.7E-04	E	yes	4.9E-03	E	no	no
95636	1,2,4-Trimethylbenzene	NA	NA		6.0E-03	E	no	no
108678	1,3,5-Trimethylbenzene	NA	NA		6.0E-03	E	no	no
108054	Vinyl acetate	NA	NA		2.00E-01	I	no	no
75014	Vinyl chloride (chloroethene)	8.80E-06	I	no	1.00E-01	I	no	no

Sources:
Hierarchy is as follows:
I = IRIS
E = EPA-NCEA provisional value
H = HEAST
A = HEAST Alternative

Notes:
If no inhalation data were available, toxicity data were extrapolated from oral studies.
Data are current as of November 2002.

* The target concentration for trichloroethylene is based on the upper bound cancer slope factor identified in EPA's draft risk assessment for trichloroethylene (US EPA, 2001). The slope factor is based on state-of-the-art methodology, however the TCE assessment is still undergoing review. As a result, the slope factor and the target concentration values for TCE may be revised further.

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APPENDIX E – RELEVANT METHODS AND TECHNIQUES

I. Introduction

This appendix provides information on sampling and analysis methodologies that can be used to help evaluate vapor intrusion into indoor air. It should be noted that not all of these methods were developed specifically for this purpose. The Office of Research and Development (ORD) is evaluating the available methods to determine their applicability, and when methods have low reliability (e.g., sub-slab sampling), developing new protocols.

The technical references provided in this appendix originate from a variety of sources including non-EPA documents which may provide regional and state site managers, as well as the regulated community, useful technical information. However, such non-EPA documents do not replace current EPA or OSWER guidance or policies.

II. Site Characterization

Characterization of a site involves the collection of data and the development of a conceptual site model (See Appendix B) to assist in making decisions on the risks posed by contaminants to critical receptors. A variety of data may be employed in the process, and the data should be assessed for their quality and usefulness in making critical decisions on the risks posed by a site. Different media may be sampled with a variety of methods and may be analyzed in a variety of ways. We recommend that experts from appropriate disciplines be assembled at an early stage to develop objectives for the site investigation and to develop a sampling and analytical plan meeting data quality objectives (DQOs).

The Office of Research and Development's National Exposure Research Laboratory (NERL) has prepared a Compact Disk (CD) entitled "Site Characterization Library, Volume 1, Release 2.5," which contains more than 20,000 pages and 84 documents of guidance for the characterization of sites that can be searched, read, and printed (EPA/600/C-02/002). The documents are readable using Adobe Acrobat software. Twenty-five software programs are also included. The CD may be obtained from the National Center for Environmental Publications (NCEP). The CD identifies the following ASTM standards for site characterization:

D 5314	Guide for Soil Gas Monitoring in the Vadose Zone
D 4696	Guide for Pore-Liquid Sampling from the Vadose Zone
D 3404	Guide to Measuring Matric Potential in the Vadose Zone Using Tensiometers
D 4944	Test Method for Field Determination of Water (Moisture) Content of Soil by the Calcium Carbide Gas Pressure Tester Methods

D 3017 Test Method for Water Content of Soil and Rock In-Place by the Nuclear Method (Shallow Depth)

D 5220 Test Method for Water Content of Soil and Rock In-Place by Neutron Depth Probe Method

D 6031 Test Method for Logging In Situ Moisture Content and Density of Soil and Rock by the Nuclear Method in Horizontal, Slanted and Vertical Access Tubes

Other relevant ASTM methods include:

D 6235 Standard Practice for Expedited Site Characterization of Vadose Zone and Around Water Contamination at Hazardous Waste Contaminated Sites

D 5730 Guide for Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone, and Groundwater

III. Groundwater Sampling and Analysis for VOCs

Prior to using groundwater data for evaluating the vapor intrusion pathway, we recommend that you establish that LNAPL is not floating on the groundwater, as the VOCs can partition directly from the pure product to the vapor phase rather than from the dissolved phase. This can be indicated by analytical results from water samples taken at the water table having values higher than the theoretical solubility for the specific LNAPL compounds present.

If possible, we recommend that groundwater samples be collected from wells screened at or across the top of the water table. This point of collection is necessary to be consistent with the derivation of the target groundwater criteria in Table 2, which assumes equilibrium partitioning between the aqueous and vapor phases and uses Henry's Law Constant to calculate source vapor concentrations corresponding to groundwater concentrations. It should be recognized that samples from groundwater monitoring wells maybe a blend of groundwater from different levels across the screened interval. This may result in either under- or over-estimation of the groundwater contaminant concentration at the top of the aquifer. For example, at site locations where concentrations are highest near the water table, the in-well blending will provide data with a negative bias (concentrations lower than representative). This may occur at locations where LNAPL is found near the water table, where recharge rates are low, or sites where there is an interface-zone plume (a fluctuating water table facilitates interactions between a vapor plume and the shallow groundwater). At other sites, shallow groundwater may have relatively low concentrations, and in-well blending will provide data with a positive bias (concentrations higher than representative). Examples include sites with a high rate of recharge from above, which can create a layer of shallow groundwater with little or no contamination that acts as a barrier to volatilization of vapors from deeper groundwater. [For more information, see Fitzpatrick, N. A., Fitzgerald, J. J. 1996. "An Evaluation of Vapor Intrusion Into Buildings Through a Study of Field Data," *Proceedings of the 11th Annual Conference on Contaminated Soils,* University of Massachusetts at Amherst.]

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Confidence in the groundwater data can be increased through the use of a narrowly screened interval across the water table, the use of low flow sampling procedures to minimize mixing, or a variety of other depth-discrete sampling protocols. Methods of sampling such as direct push using a Geoprobe or cone penetrometers should concentrate on the upper few feet of the ground water.

There are numerous ASTM standards for groundwater sampling. Assuming wells already exist for sampling VOCs, the following standards are recommended:

D 5980	Standard Guide for Selection and Documentation of Existing Wells for Use in Environmental Site Characterization and Monitoring
D 6634	Standard Guide for the Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells
D 5903	Guide for Planning and Preparing a Ground-Water Sampling Event
D 6452	Guide for Purging Methods for Wells Used for Ground-Water Quality Investigations
D 4448	Standard Guide for Sampling Ground-Water Monitoring Wells
D 6771	Standard Practice for Low-Flow Purging and Sampling for Wells and Devices Used for Ground-Water Quality Investigations
D 6564	Standard Guide for Field Filtration of Ground Water Samples
D 6517	Standard Guide for Field Preservation of Ground Water Samples
D 3694	Practices for Preparation of Sample Containers and for Preservation of Organic Constituents
D 6089	Guide for Documenting a Ground-Water Sampling Event

The following ASTM standards are useful if a monitoring system is not already in place:

D 5612	Standard Guide for Quality Planning and Field Implementation of a Water Quality Measurement Program
D 5730	Standard Guide for Site Characterization for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone and Ground Water
D 6286	Standard Guide for Selection of Drilling Methods for Environmental Site Characterization

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D 6001 Standard Guide for Direct-Push Water Sampling for Geoenvironmental Investigations

D 5092 Standard Practice for Design and Installation of Ground-Water Monitoring Wells in Aquifers

D 5521 Standard Guide for Development of Ground-Water Monitoring Wells in Granular Aquifers

Other Related ASTM Standards:

D 6312 Standard Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs

D 5241 Standard Practice for Micro-Extraction of Water for Analysis of Volatile and Semi-Volatile Organic Compounds in Water

D 5314 Standard Guide for Soil Gas Monitoring in the Vadose Zone

D 4696 Standard Guide for Pore-Liquid Sampling from the Vadose Zone

IV. Indoor Air Sampling and Analysis

Indoor air sampling and analysis provide the most direct estimate of inhalation exposures. However, source attribution for the many compounds typically present in indoor air can be challenging. Constituents of indoor air can originate from indoor emission sources, from ambient (outdoor) air contributions, as well as from possible vapor intrusion of contaminated groundwater. Each of these sources can introduce concentrations of volatile chemicals to the indoor environment sufficient to pose an unacceptable health risk. In addition, concentrations of compounds found in indoor air are often subject to temporal and spatial variations, which may complicate estimates of exposure. If source attribution is pursued, then we recommend that the various potential sources contributing to the total concentration of a compound be identified. This is typically very challenging and may involve a series of measurements, or actions, whose purpose is to isolate the individual source contributions. Before conducting an indoor air sampling plan, we recommend consideration be made to other management options, such as proactive exposure controls, which may be cost competitive. Appendix A provides guidance in executing the DQO process for planning an indoor air-monitoring program.

Prior to indoor air sampling, we recommend conducting an inspection of the residence and an occupant survey to adequately identify the presence of any possible indoor air emission sources of (or occupant activities that could generate) target VOCs in the dwelling (see Appendices H & I). An indoor air quality survey has several components, and we recommend that it be consistent with data quality protocols appropriate for risk assessment (see Risks Assessment Guidance for Superfund Part B http://www.epa.gov/superfund/program/risk/ragsb/index.htm or EPA/540/R-

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92/003). The Massachusetts Department of Environmental Protection (MA DEP) has prepared an *Indoor Air Sampling and Evaluation Guide (April 2002)* which is available at the following URL: http://www.state.ma.us/dep/ors/files/indair.pdf.

Many aspects of the protocols used for ambient air can also be applied to indoor air sampling (e.g., EPA TO-15 and TO-17 methods). Specially treated stainless steel evacuated canisters or adsorbent tubes are appropriate for sampling and we recommend that they be combined with an analytical method capable of obtaining the detection limits identified in the DQO process. To facilitate a reliable comparison of analytical results, a standard condition for sampling is recommended. Some guidance in establishing a standard monitoring condition is given in the following paragraphs.

We recommend that sampling units be placed within the normal breathing zone, 2 to 5 feet above the floor, in the lowest inhabited area. It is generally advisable to collect at least one 24-hour sample in both the probable place of highest concentration (e.g., basement) and in the main living area. Two or more sampling events at each location are desirable. Typically, we recommend that the house be closed (windows and doors shut) 12 to 24 hours before the measurements begin and the use of appliances that induce large pressure differences (e.g. exhaust fans, clothes dryers, operating fireplaces) be avoided during this time. Additionally, we recommend avoiding sampling locations adjacent to windows and air supplies.

We recommend gas sampling that will be used for direct assessment of vapor intrusion meet or exceed requirements for demonstrating method acceptability as specified in EPA Methods TO-15 (canister-based sample collection) and TO-17 (sorbent tube-based sample collection) or appropriately modified to achieve a lower method detection limit (MDL) corresponding to a given life-time risk level. Note: To achieve detection at or below the published 10^{-5} to 10^{-6} risk levels for many target compounds, the MDLs for TO-15 or TO-17, in our judgment, must be considerably below 0.5 ppbv.

To achieve TO-15 and TO-17 method acceptability, we recommend that a sampling and analysis protocol meet the recommended performance criteria for an enhanced method detection limit, replicate precision, and audit accuracy at compound concentrations corresponding to the 10^{-5} or 10^{-6} risk levels, and special attention be paid to quality control measures. Sufficiently low sample container blanks, analytical system blanks, analytical interferences, etc., are all implied in the ability to meet the technical acceptance criteria.

To ensure reliable measurements are obtained, we recommend that multiple simultaneous samples (more than one canister or sorbent tube) be taken for every sampling event and from the same inlet so that variability in nominally identical samples can be documented. Also, we recommend that knowledge of the performance of the analytical system be demonstrated, including blank response, the MDLs, calibration of the target compounds at or near the sample concentration range, and the likelihood of interferences. These are common sense considerations that are covered in TO-15 and TO-17, but call for special attention at the low concentration levels being considered.

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Note: At this point in the development of the best approach to sorbent tube sampling (TO-17), reduction of co-collected water on the sorbent tubes is sometimes important to achieve a linear analytical response such as with ion trap mass spectrometers. Therefore, we recommend that preliminary experiments be performed to document the effect of different water vapor levels on analytical performance. Also, the interaction of target compounds with reactive compounds, e.g. ozone, depends on the extent to which the reactive compounds exist in the indoor air and the reaction rates. Until this specific problem with sampling is addressed, we recommend that the ozone concentration be determined at every sampling event. Also, an interaction of ozone with adsorbed compounds can destroy the compound. Certain target compounds have been tested for this (see McClenny, W.A., Oliver, K.D., Jacumin, H.H., Jr., and Daughtrey, E.H., Jr., 2002, Ambient volatile organic compound (VOC) monitoring using solid adsorbants - recent U.S. EPA developments, JEM 4(5) 695 – 705).

Recommended publications:

Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition, EPA/625/R-96/010b

- Method TO-15, Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). pp.15-1 through 15-62

- Method TO-17, Determination of Volatile Organic Compounds in Ambient Air using Active Sampling on Sorbent Tubes. pp. 17-1 through 17-49

- Compendium of Methods for the Determination of Air Pollutants in Indoor Air, EPA/600/4-90-010

V. Soil Gas Sampling

Soil gas sampling and analysis results tend to be more reliable at locations and depths where high contaminant concentrations are present and where the soils are relatively permeable. Reliability of the results tends to be lower in lower permeability settings and when sampling shallow soil gas. In both cases, leakage of atmospheric air into the samples is a valid concern. Consequently, it is recommended that samples collected at depths less than 5 feet below ground surface (bgs) not be used for this analysis, unless they are collected immediately below the building foundation several feet in from the edge (e.g., subslab samples). Reliability of soil gas sampling can be assessed by: a) measuring a vertical profile and inspecting to see if measured concentrations decrease with increasing distance from the vapor source, and b) checking to see if vapor concentrations correlate qualitatively and quantitatively with available groundwater concentration data. For example, with groundwater sources the highest soil gas concentrations should correlate with the highest groundwater concentrations, and vapor concentrations collected immediately above groundwater should not exceed the value calculated using Henry's Law. Parallel analysis of oxygen, carbon dioxide, and nitrogen in soil gas samples can often be used to help assess the reliability of a given sample result. Reliability is typically improved by using

fixed probes and by ensuring that leakage of atmospheric air into the samples is avoided during purging or sampling. To avoid dilution of the sampling region, we recommend using the minimum purge volume deemed adequate to flush the sampling system. With respect to the spatial distribution of sampling points, close proximity to the building(s) of concern is generally preferred; however, it may be possible to reasonably estimate concentrations based on data from soil gas samples collected about a larger area. Additionally, as vapors are likely to migrate upward preferentially through the coarsest and driest material, we recommend soil gas samples be collected from the most permeable zones in the vadose zone underlying the inhabited buildings. Concentrations should be lower in the high permeability zones than the low permeability zones.

The velocity at which soil gas should be sampled is influenced by the soil permeability, and the volume of sample taken will determine the zone of soil that is sampled. The effects of low- versus high-velocity and micro- versus macro-volume soil gas sampling techniques are currently being evaluated.

Measurement of VOCs in the Subslab Soil Gas

Subslab sampling may entail drilling a series (e.g., 3 to 5) of small diameter (e.g., 9/16") holes in the foundation of a residential building. It may be advantageous to install flush mounted stainless steel or brass vapor probes in contaminant free cement. We recommend sampling be performed using EPA Method TO-15 or TO-17.

The preferred measurement location is in the central portion of the slab, well away from the edges where dilution is more likely to occur. We recommend the hole be plugged with a material such as tape or pliable caulk (VOC free) immediately after drilling the hole to minimize the disturbance of the sub slab concentrations. When drilling the hole, care should be taken not to puncture the surface of soil underneath. In cases where there is aggregate soil underneath the foundation, this care may not be important, but if the soil has a slightly compacted layer on top with a slight subsidence under the slab this compacted layer may actually provide some resistance to the entry of soil gas from underneath. In this case, a subslab sample can be collected by slowly pulling a volume of gas from the void of the subsidence. This initial measurement may be representative of the soil gas typically entering the house. After the subslab with undisturbed soil has been sampled, it may be instructive to penetrate the surface of the soil and resample. We recommend the subslab samples be collected at several locations to obtain representative values. It is important to not disturb the subslab region by applying excessive pressures that might induce dilution of vapors in this region. Significant pressures might result from excessive slamming of doors, or from appliances such as: exhaust fans, clothes dryers, downdraft grills, ceiling or roof mounted attic fans, or certain combinations of open windows on a windy day. If the subslab region is disturbed, it may require many hours to return to a steady state condition.

Additional points to consider before drilling into the foundation are whether or not the home has an existing vapor barrier, or is a tension slab. In either case, alternative sampling methods may be preferable.

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Measurement of VOC's in soil gas using slam bar methods

Slam bar methods have been widely used to measure contaminants in soil gas. The results of these measurements have been highly variable. Because this technique is frequently used for relatively shallow sampling, it is, in our judgment, prone to errors from dilution by surface air. This is especially true when the hole is punched or drilled with one instrument that is then replaced by a measurement probe (sometime of smaller diameter). We recommend great care be taken to ensure that leakage air does not enter the sample. Only the volume of air sufficient to flush the probe and sampling line should be extracted before collecting the sample. The larger the purge/sample volume, the larger the subsurface area of influence; if the contamination is contained within non-preferential flow paths or small discrete locations, a large purge/sample volume will dilute the concentration of contaminants.

Measurement of VOC's in soil gas using push probe methods

This approach seems to be emerging as a powerful tool for conducting soil gas measurements. OSWER is working with ORD and will update this section on the EPA/OSWER website as further refinements of these methods are developed.

Recommend publications:

Soil Vapor Extraction Technology: Reference Handbook - Soil Vapor Extraction Technology: Reference Handbook March 1990. Environmental Protection Agency, Risk Reduction Engineering Lab. EPA/540/2-91/003

VI. Soil Sampling and Analysis

Soil sampling and analysis is not recommended for assessing whether or not the vapor intrusion pathway is complete. This is because the uncertainties associated with soil partitioning calculations, as well as the uncertainties associated with soil sampling and soil chemical analyses for volatile organic chemicals, are so great that, that in our judgment, use of soil concentrations for assessment of this pathway is not technically defensible. Thus, soil concentration criteria were not derived and the use of soil criteria is not encouraged in this guidance. Soil concentration data might, however, be used in a qualitative sense for delineation of sources provided the soil samples are preserved immediately upon collection with methanol. For example, high soil concentrations (e.g. >1000 mg/kg TPH) would definitely indicate impacted soils; unfortunately, the converse is not always true and we recommend that non-detect analytical results not be interpreted to conclude the absence of a vapor source.

VII. Other Issues

We recommend that detection limits be considered when choosing which media to sample and how to interpret the results. The properties of some chemicals and the biases in the analytical methods may be such that the sensitivity of detection is higher in one medium than another. For

example, a high Henry's constant (H>1) chemical might be detectable in soil gas when the concentration in groundwater falls below the detection limit (e.g., vinyl chloride).

We recommend that transformation products also be considered when selecting the chemicals of concern. For example, 1,1,1-trichloroethane (111TCA) may be abiotically converted to 1,1-dichloroethene (11DCE) in groundwater, so that we recommend looking for both chemicals at 111TCA spill sites.

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APPENDIX F

EMPIRICAL ATTENUATION FACTORS AND RELIABILITY ASSESSMENT

1. Introduction

The empirical attenuation factors used in this guidance were derived through review of data from sites with paired indoor air and soil gas and/or groundwater concentrations. These data have been compiled into a database with the structure and elements illustrated in Figure F-1.

The database contains information from 15 sites (CO - 5 Sites; CA - 1 Site; CT – 1 Site; MA – 7 Sites; and MI – 1 Site). Fifteen VOCs are represented: BTEX, Chloroform, 1,1-Dichloroethane, 1,2-Dichloroethane, 1,1-Dichloroethylene, cis-1,2-Dichloroethylene, trans-1,2-Dichloroethylene, Tetrachloroethylene, 1,1,1- Trichloroethane, 1,1,2-Trichloroethane, Trichloroethylene and Vinyl chloride. The result is a database with 274 total residence and chemical combinations, 35 of which represent BTEX compounds and the remaining 239 represent chlorinated hydrocarbons. Groundwater data are available for the entire set of residence and chemical combinations. Soil gas data are available only for 40 of the residence and chemical combinations.

The information in the database was used to calculate groundwater-to-indoor air and soil gas-to-indoor air attenuation factors for each of the chemicals measured at each of the residences monitored. The distributions of these calculated attenuation factors were used to define a conservative empirical attenuation factor for each medium, as described in Sections 2, 3, and 4 below.

An assessment was performed using the same database to determine the reliability of the selected attenuation factors for screening in residences with indoor air concentrations exceeding the target levels corresponding to a cancer risk of 10^{-6} and 10^{-5}. The reliability assessment was performed by determining the number of false negative and false positives corresponding to the selected attenuation factor using the guidelines described in Section 6 below.

2. Calculation of Attenuation Factors

The attenuation factor represents the ratio of the indoor air concentration measured in a residence to the vapor concentration measured in the subsurface materials underlying or adjacent to the residence. For soil gas, the attenuation factor (α) is calculated simply as:

$$\alpha = \frac{C_{indoor}}{C_{soil\ gas}}$$

where

C_{indoor} = measured indoor air concentration [ug/m^3]
$C_{soil\ gas}$ = measured soil gas concentration [ug/m^3]

For groundwater, the attenuation factor is calculated as:

$$\alpha = \frac{C_{indoor}}{C_{groundwater} H_c}$$

where

$C_{groundwater}$ = measured groundwater concentration [ug/L] x 1000 L/m^3
H_c = dimensionless Henry's Law Constant [--]

Henry's Law Constant is used to convert the measured groundwater concentration to a corresponding equilibrium soil gas concentration. Field data suggest that this conversion may result in over prediction of the soil gas concentration (by as much as a factor of ten) directly above the contaminated groundwater. However, this is not always the case and consequently Henry's Constant is used here without a correction factor.

In the database, attenuation factors are calculated using only those residences and chemicals for which both the indoor air and subsurface measurements were above the chemical's method detection limit (MDL). Because the subsurface concentrations are generally greater than the measured indoor air concentrations, the calculated attenuation factors are values less than one.

3. Groundwater-to-Indoor Air Attenuation Factor

The distribution of groundwater-to-indoor air attenuation factors is shown in Figures F-2 and F-3. Figure F-2 shows the distribution of attenuation factors for all residences in the database with associated measured indoor air and groundwater concentrations above the chemicals' MDLs. The calculated attenuation factors range from 10^{-1} to 10^{-7}. This range includes attenuation factors calculated for homes with high indoor air concentrations as well as for homes with indoor air concentrations at levels typical of background concentrations (Table F-1). Figure F-3 compares the distribution shown in Figure F-2 to the distribution of the subset of attenuation factors corresponding to residences with indoor air concentrations greater than the typical background levels (e.g., geometric mean of the mean background values shown in Table F-1). As can be seen in Figure F-3, fewer than 5% of the residences with indoor air concentrations above typical background levels have attenuation factors greater than 0.001 (1/1000). This means that for 95% of the residences in the database, the groundwater-to-indoor air attenuation factor is less than 0.001 (1/1000) and, consequently, this value (0.001) is considered to be a generally reasonable upper-bound value.

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4. Soil Gas-to-Indoor Air Attenuation Factor

The shallow soil gas to indoor air attenuation factor represents the ratio of the indoor air concentration to the soil gas concentration at some shallow depth. For the purposes of this guidance, shallow soil gas samples are defined as those obtained either from directly below the foundation or from depths less than 5 feet below foundation level. Figure F-4 shows the distribution of subslab-to-indoor air attenuation factors for the subset of residences with indoor concentrations greater than the subslab concentration measured below the residence's foundation. As can be seen in the plot, approximately 15% of the residences have attenuation factors greater than 0.1 (1/10), or conversely, about 85% of the residences have attenuation factors smaller than 0.1 (1/10). Consequently, an attenuation factor of 0.1 was used to represent a generally reasonable upper-bound value for the case where the soil gas concentration immediately beneath a foundation is used (e.g., the indoor air concentration would not be expected to exceed 1/10 of the concentration immediately below the foundation). This value is also supported by an analysis of the dilution that occurs due to ventilation of a house. An attenuation factor of 0.1 suggests that 10% or less of the air exchanged in a house originates from the subsurface. This value is conservatively assumed to apply to shallow soil gas samples (< 5 feet below foundation level) as well as subslab samples.

Deep soil gas samples are defined for the purposes of this guidance as those obtained just above the water table or from depths greater than 5 feet below foundation level. A smaller attenuation factor than that used for shallow soil gas is warranted as the deep soil gas samples represent a more direct measurement of the source vapor concentration and are subject to less variability than is observed for shallow soil gas samples. On the other hand, a more conservative value than that used for groundwater is warranted, as there is not the added safety factor incorporated in the groundwater attenuation factor, which assumes equilibrium partitioning of chemicals between groundwater and soil vapor (Henry's Law). Consequently, a value of 0.01 was selected for deep soil gas.

5. BTEX versus Chlorinated Hydrocarbon Attenuation Factors

To be conservative, the recommended criteria developed for this guidance have been established assuming that the chemicals do not degrade as they migrate through the vadose zone. It should be recognized that many chemicals of interest do biodegrade. For example, petroleum hydrocarbon vapors will biodegrade in the presence of oxygen, and field studies have shown this biodegradation to be very significant in some settings. In contrast, analysis of data from sites impacted with chlorinated solvents suggest that degradation is insignificant for these compounds. The impact of biodegradation can be seen in the distribution of attenuation factors for BTEX compounds versus chlorinated hydrocarbons (Figure F-5). Figure F-5 suggests a three-fold to ten-fold decrease in attenuation factor for BTEX compounds.

Unfortunately, the significance of the biodegradation has also been highly variable, and the factors that determine its significance are not yet fully understood. In a very general sense, it is expected that aerobic biodegradation will have limited effect in settings where

oxygen re-supply is limited, and also will have little effect on the attenuation factors used for soil gas samples collected near a building. At this time, we recommend that the significance of biodegradation be determined through collection of vertical soil gas profiles beneath the buildings of concern. The occurrence of aerobic biodegradation will be reflected qualitatively in the oxygen and contaminant soil vapor profiles, and the quantitative effects can be estimated by the methods described in Johnson et al. (1999), or other defensible analysis methods. It is unlikely that the extensive site-specific information required to determine the influence of biodegradation will be available in the initial stages of site characterization. Therefore, we believe that it is generally prudent to assume that biodegradation is not a factor when screening sites for vapor intrusion issues.

6. Reliability Assessment

The reliability of the evaluation approach used in Questions 4, 5, and 6 of this guidance was assessed using the database described above in Section 1 of this appendix. For the assessment at the generic screening level (Question 4), the target levels in Tables 2(a) and 2(b) were used. For the assessment of Question 5, the target levels in Tables 3(a) and 3(b) were used. For Question 6, the Johnson and Ettinger Model was applied as described in Appendix G using the updated default model parameters. The following sections briefly describe the analysis and results. This analysis shows that the evaluation approach used in this guidance yields reliable results at both the 10^{-5} and 10^{-6} cancer risk levels when assessing the vapor intrusion pathway at all sites reviewed.

6.1 Analysis Approach

Cancer risk levels at both the 10^{-5} and 10^{-6} levels were evaluated. Table 2 was used to select target levels for evaluation of Question 4. For Question 5, the appropriate attenuation factor to use when selecting screening levels from Table 3 was determined from the figures 3a and 3b in Question 5 of the guidance as a function of site-specific SCS soil types and depth to groundwater. For the Question 6 assessment, information on foundation type (either slab-on-grade or basement) and building mixing height was incorporated into the analysis (basement defaults were used for buildings with crawl spaces) and a site-specific attenuation factor was calculated.

The assessment was performed by determining the number of false negative and false positives obtained using the most recently available toxicity data. As shown in Table F-2, a false negative occurs when a chemical's measured indoor air concentration exceeds the target level, but the measured groundwater (or soil gas) concentration does not. False negatives may appear if indoor or ambient (outdoor) sources of VOCs are present and they exceed the indoor air target level at the selected risk level. A false positive occurs when a chemical's measured indoor air concentration is below the target level, but the measured groundwater (or soil gas) concentration is above the target level. Correct positives and correct negatives are defined in a similar fashion, as shown in Table F-2.

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6.2 Results

In order to effectively understand the results, it is important to differentiate between samples, buildings, and sites. There are seven sites evaluated in this analysis (Alliant, Eau Claire, Hamilton-Sunstrand, LAFB, MADEP, Mountain View, and Uncasville). Each site has one or more buildings. For example, the Alliant site has only one building. LAFB has 13 buildings and Mountain View has seven buildings. Each building has its own unique address. Several samples were taken at each building. Each sample consists of paired indoor air and groundwater concentrations for a unique chemical at a certain building. The number of samples and the number of chemicals identified in these samples varies by building.

The results are grouped into two types of tables. Tables F-3 (risk level 10^{-5}) and F-5 (risk level 10^{-6}) organize the results by building at each site. It shows whether or not a building has a correct negative, correct positive, false negative, or false positive result. An important note regarding Tables F-3 and F-5 is the difference between buildings that are not applicable for vapor intrusion analysis ("NA" is added to the results of these buildings) and buildings with wet basements. Buildings that are not applicable are those where the depth from the bottom of the foundation (whether it be a basement or slab-on-grade) to groundwater contamination is less than 1.5 meters (5 feet). This is one of the precluding factors listed in the guidance. We still included results for these buildings, but marked their results with an "NA" to indicate that they would be excluded from this analysis according to protocols set forth in the guidance. The false negative, false positive, correct negative, and correct positive results for non-NA buildings are summed at the bottom of each table.

The second set of results presents outcomes by chemical at each site. Tables F-4 (risk level 10^{-5}) and F-6 (risk level 10^{-6}) show the number of false positive and false negative outcomes for each chemical at each site. They do not indicate whether the false results occur in just one or two buildings at the site, or evenly across all buildings. It is important to note that the numbers in these tables are counts of samples, not of buildings. Therefore, it is possible to have a false negative result for a chemical at a particular site, but each building at that site can have correct positive results based on the outcomes for other chemicals. It is also important to note that results for those samples that are considered not applicable (NA) according to the criteria discussed in the guidance are not included in this table.

Tables F-3 and F-5 show that the evaluation approach used in this guidance yields no false negatives with respect to sites or buildings at either the 10^{-5} or 10^{-6} cancer risk level. Tables F-4 and F-6 show that for most chemicals either no or few false negatives are obtained, with the exception of tetrachloroethene and 1,2-dichloroethane. These two chemicals show a number of false negatives, especially at the 10^{-6} cancer risk level. It is important to note, however, that both of these chemicals are typically found as background contaminants, which may account for some of the false negatives. Several of the chemical-specific false negative results shown in Tables F-4 and F-6 also appear to

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result from limiting the ground water target concentration to the MCL if the calculated target concentration would be less than the MCL.

Table F-1. Background indoor air concentrations for selected volatile organic compounds. All concentrations expressed in ug/m^3.

Compound	Shah and Singh (1988)	Samfield (1992)	Brown et al. (1994)	NOPES (1990)	Sheldon (1992)	MADEP (September 1998)	*EPA IAQ Reference Manual (July 1991)*	Foster et al., (2002)
1,1,1-Trichloroethane	271.4	-	-	-	-	30	70	0.7
1,1,2,2-Tetrachloroethane	0.098	-	-	-	-	0.01	-	-
1,1,2-Trichloroethane	-	-	-	-	-	-	-	RL (0.064)
1,1-Dichloroethylene	-	-	-	-	-	6.5	-	RL (0.08)
1,2-Dichloroethane	-	-	-	-	-	-	-	0.07
Acetaldehyde	-	9.6	-	-	-	-	-	-
Acetone	19.3	-	-	-	-	6	-	-
Benzene	16.8	8.2	8.0	-	2.2	21	14	4.08
Carbon Tetrachloride	2.6	12.0	-	-	0.5	1	5	-
Chlordane	-	2.8	-	0.18	-	-	-	-
Chlorobenzene	-	-	-	-	-	10	-	-
Chloroform	4.1	8.0	10.0	-	-	3	6	2.1
Cumene	0.2	5.1	-	-	-	-	-	-
DDE	-	-	-	0.001	-	-	-	-
Dichlorobenzenes	-	31.0	8.0	-	1.0	0.5	58	-
Ethylbenzene	12.7	13.8	5.0	-	-	10	14	-
Heptachlor	-	0.7	-	0.07	-	-	-	-
Hexachlorobenzene	-	0.0	-	0.0004	-	-	-	-
Hexane	-	33.0	12.0	-	-	-	-	-
Methoxychlor	-	-	-	0.0002	-	-	-	-
Methylene Chloride	-	342.0	17.0	-	15.0	10	-	0.98
Methylethylketone (2-butanone)	9.2	7.0	4.0	-	-	42	-	-
Methylisobutylketone (4-methyl-2-pentanone)	-	-	-	-	-	2	-	-
Naphthalene	-	11.0	-	-	-	-	-	-
Styrene	-	1.8	-	-	1.0	5	6	-
Tetrachloroethylene	21.1	9.5	7.0	-	0.3	11	28	1.62
Toluene	28.3	56.0	37.0	-	-	29	61	-
Trichlorobenzenes	0.5	-	-	-	-	-	-	-
Trichloroethylene	7.4	-	-	-	-	5	9	0.15
Vinyl chloride	-	-	-	-	-	-	-	0.01
Xylenes	-	25.0	24.0	-	6.0	3	14	-

Shah and Singh (1988): ES&T, Vl. 22, No.12, pp. 1381-1388, 1988

Samfield (1992): EPA-600-R-92-025, 1992.

Brown et al. (1994): Indoor Air, 4:123-134, 1994.

NOPES (1990): EPA/600/3-90/003, January 1990.

Sheldon (1992): California Air Resources Board, Final Report, January 1992.

MADEP (September 1998): From: Background Documentation for the Development of MCP Numerical Stds" April 1994, Table 4.2, except 1,1-dichloroethene (EPA TEAM study) and methylene chloride (Stolwijk, JAJ, 1990)

EPA IAQ Reference Manual (July 1991): Results from Wallace (1987), except toluene: Seifert & Abraham (1982).

Foster et al., (2002): Foster, S.J, J.P. Kurtz, and A.K. Woodland, Background indoor air risks at selected residences in Denver, Colorado, 2002.

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Table F-2. Evaluation criteria for the reliability assessment.

Measurement	Relationship	Vapor Intrusion Screening Level	Condition
C(GW)	>	GWSL	CORRECT POSITIVE
C(IA)	>	IASL	
C(GW)	<	GWSL	CORRECT NEGATIVE
C(IA)	<	IASL	
C(GW)	<	GWSL	FALSE NEGATIVE
C(IA)	>	IASL	
C(GW)	>	GWSL	FALSE POSITIVE
C(IA)	<	IASL	

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Table F-3
False Negative and False Positive Indoor Air Predictions Based on Comparison of Groundwater Concentrations to Target Levels, by Building at Each Site

$R=1x10^{-5}$

Site Name	Address	Vapor Intrusion Q4[1]	Vapor Intrusion Q5[2]	Compound(s) Responsible for False Result [3]
Alliant		NA(CP)	NA(CP)	
Eau Claire	Residence F	NA(CP)	WB	
	Residence K	NA(CP)	WB	
	Residence S	NA(CP)	WB	
Hamilton-Sunstrand	6800 Fern Dr.	CP	CP	
	6800 Osage St.	CP	CP	
	6800 Ruth Way	CP	CP	
	6801 Avrum Dr.	CP	CP	
	6801 Fern Dr.	CP	CP	
	6810 Jordan Dr.	CP	CP	
	6811 Ruth Way	CP	CP	
	6820 Fern Dr.	CP	CP	
	6821 Mariposa St.	CP	CP	
	6821 Pecos	CP	CP	
	6831 Navajo St.	CP	CP	
	6831 Zuni St.	CP	CP	
	6840 Mariposa	CP	CP	
LAFB	UA02	CP	CP	
	UA03	CP	CP	
	UA04	CP	CP	
	UA05	CP	CP	
	UA18	CP	CP	
	UA19	CP	CP	
	UA21	CP	CP	
	UA22	CP	CP	
	UA23	CP	CP	
	UA24	CP	CP	
	UA25	CP	CP	
	UA26	CP	CP	
	UA28	FP	FP	Trichloroethylene
MADEP	0907 A Hull	NA(CP)	WB	
	0907 B Hull	NA(CP)	WB	
	1019 Lynnf	NA(FP)	NA(FP)	Benzene, Ethylbenzene, Toluene
	11707 Quincy	NA(CP)	NA(CP)	
	12092 B Marble	CP	CP	Benzene
	1525 A Marble	NA(CP)	NA(CP)	
	1525 B Marble	NA(CP)	NA(CP)	
	2797 A Tewks	NA(FP)	NA(FP)	Benzene, Ethylbenzene, Toluene
	2797 B Tewks	NA(FP)	NA(FP)	Benzene, Ethylbenzene, Toluene
Mountain View	Residence 1	CP	CP	
	Residence 2	CP	CP	
	Residence 3	CP	CP	
	Residence 4	CP	CP	
	Residence 6	CP	CP	
	Residence 7	CP	CP	
	Residence 8	CP	CP	
Uncasville	Residence A	NA(CP)	NA(CP)	
	Residence B	NA(CP)	NA(CP)	
	Residence D	NA(CN)	NA(CN)	
	Residence E	NA(CP)	NA(CP)	

Key:
CP=Correct Positive; CN = Correct Negative
FP=False Positive; FN=False Negative
NA=Not applicable due to precluding factor--depth from foundation to groundwater contamination is less than 1.5 m.
WB=Wet Basement. This condition precludes the use of Figure 3 (for Q5).

Notes:
[1] Site data was compared to indoor air and groundwater screening values in Table 2.
[2] Site data was compared to indoor air and groundwater screening values in Table 3. The appropriate attenuation factor in this
[3] When false positive or false negative outcomes resulted with both Q4 and Q5, the same compounds were responsible for the false outcome in each scenario.

Table F-3 (continued)
Summary Table
False Negative and False Positive Indoor Air Predictions Based on Comparison of Groundwater Concentrations to Target Levels, by Building at Each Site
R=1x10^{-5}

	Q4		Q5	
	Number	**Percent**	**Number**	**Percent**
Total CP and CN	33	97.1%	33	97.1%
Total FP	1	2.9%	1	2.9%
Total FN	0	0.0%	0	0.0%
Total NA and WB	16	47.1%	11	32.4%
Total Number of Buildings	34		34	

Key:

CP=Correct Positive; CN = Correct Negative

FP=False Positive; FN=False Negative

NA=Not applicable due to precluding factor--depth from foundation to groundwater contamination is less than 1.5 m.
WB=Wet Basement. This condition precludes the use of Figure 3 (for Q5).

Notes:

[1] Site data was compared to indoor air and groundwater screening values in Table 2.

[2] Site data was compared to indoor air and groundwater screening values in Table 3. The appropriate attenuation factor in this analysis was obtained from Figure 3.

[3] When false positive or false negative outcomes resulted with both Q4 and Q5, the same compounds were responsible for the false outcome in each scenario.

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Table F-4
Frequency of False Negative and False Positive Indoor Air Predictions Based on Comparison of Ground Water Concentrations to Target Levels, by Chemical[1]
Risk = $1x10^{-5}$

	Location	Benzene			1,1- Dichloroethane			1,2-Dichloroethane			1,1-Dichloroethylene			cis-1,2-Dichloroethylene[2]			trans-1,2-Dichloroethylene[2]			Ethyl Benzene*		
		Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN
VI Q4 [3]	Alliant	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	--	--	--	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	--	--	--	--	--	--
	LAFB	--	--	--	13	0	0	13	0	1	13	0	0	13	0	0	13	0	0	--	--	--
	Uncasville	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Total	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**1**	**26**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**	**1**	**0**	**0**
VI Q5 [4]	Alliant	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	--	--	--	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	--	--	--	--	--	--
	LAFB	--	--	--	13	0	0	13	0	1	13	0	0	13	0	0	13	0	0	--	--	--
	Uncasville	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Total	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**1**	**26**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**	**1**	**0**	**0**

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Table F-4 (continued)
Frequency of False Negative and False Positive Indoor Air Predictions Based on Comparison of Ground Water Concentrations to Target Levels, by Chemical[1]
Risk = $1x10^{-5}$

	Location	Tetrachloroethylene*			Toluene			1,1,1-Trichloroethane			1,1,2-Trichloroethane			Trichloroethylene*			Vinyl chloride*			Xylene[2]		
		Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN
VI Q4 [3]	Alliant	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	--	--	--
	LAFB	13	0	4	--	--	--	13	0	0	13	0	0	13	1	0	9	0	0	--	--	--
	Uncasville	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	--	--	--	1	0	0	--	--	--	--	--	--	0	0	0	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	7	0	0	--	--	--	--	--	--
	Total	**13**	**0**	**4**	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**	**33**	**1**	**0**	**9**	**0**	**0**	**1**	**0**	**0**
VI Q5 [4]	Alliant	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	--	--	--
	LAFB	13	0	4	--	--	--	13	0	0	13	0	0	13	1	0	9	0	0	--	--	--
	Uncasville	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	--	--	--	1	0	0	--	--	--	--	--	--	0	0	0	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	7	0	0	--	--	--	--	--	--
	Total	**13**	**0**	**4**	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**	**33**	**1**	**0**	**9**	**0**	**0**	**1**	**0**	**0**

Key:
FP=False Positive; FN=False Negative
Notes:
[1] For each chemical we indicate the total number of samples at each site for each chemical and the number of samples with False Positive or False Negative results at that site across all buildings. "--" means the chemical was not found at any building at that site.
[2] Toxicity values from oral studies were used to develop screening levels for this chemical.
[3] Site data was compared to indoor air and ground water screening values in Table 2.
[4] Site data was compared to indoor air and ground water screening values in Table 3.
* Ground water target concentration for this compound is based on the Maximum Contaminant Level (MCL) in drinking water.

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Table F-5
False Negative and False Positive Indoor Air Predictions Based on Comparison of Groundwater Concentrations to Target Levels, by Building at Each Site
$R=1x10^{-6}$

Site Name	Address	Vapor Intrusion Q4[1]	Vapor Intrusion Q5[2]	J&E Site Specific [3]	Compound(s) Responsible for False Result [4]
Alliant		NA(CP)	NA(CP)	NA(CP)	
Eau Claire	Residence F	NA(CP)	WB	WB	
	Residence K	NA(CP)	WB	WB	
	Residence S	NA(CP)	WB	WB	
Hamilton-Sunstrand	6800 Fern Dr.	CP	CP	CP	
	6800 Osage St.	CP	CP	CP	
	6800 Ruth Way	CP	CP	CP	
	6801 Avrum Dr.	CP	CP	CP	
	6801 Fern Dr.	CP	CP	CP	
	6810 Jordan Dr.	CP	CP	CP	
	6811 Ruth Way	CP	CP	CP	
	6820 Fern Dr.	CP	CP	CP	
	6821 Mariposa St.	CP	CP	CP	
	6821 Pecos	CP	CP	CP	
	6831 Navajo St.	CP	CP	CP	
	6831 Zuni St.	CP	CP	CP	
	6840 Mariposa	CP	CP	CP	
LAFB	UA02	CP	CP	CP	
	UA03	CP	CP	CP	
	UA04	CP	CP	CP	
	UA05	CP	CP	CP	
	UA18	CP	CP	CP	
	UA19	CP	CP	CP	
	UA21	CP	CP	CP	
	UA22	CP	CP	CP	
	UA23	CP	CP	CP	
	UA24	CP	CP	CP	
	UA25	CP	CP	CP	
	UA26	CP	CP	CP	
	UA28	CP	CP	CP	
MADEP	0907 A Hull	NA(CP)	WB	WB	
	0907 B Hull	NA(CP)	WB	WB	
	1019 Lynnf	NA(CP)	NA(CP)	NA(CP)	
	11707 Quincy	NA(CP)	NA(CP)	NA(CP)	
	12092 B Marble	CP	CP	CP	
	1525 A Marble	NA(CP)	NA(CP)	NA(FN)	Trichloroethylene
	1525 B Marble	NA(CP)	NA(CP)	NA(FN)	Trichloroethylene
	2797 A Tewks	NA(CP)	NA(CP)	NA(CP)	
	2797 B Tewks	NA(CP)	NA(CP)	NA(CP)	
Mountain View	Residence 1	CP	CP	CP	
	Residence 2	CP	CP	CP	
	Residence 3	CP	CP	CP	
	Residence 4	CP	CP	CP	
	Residence 6	CP	CP	CP	
	Residence 7	CP	CP	CP	
	Residence 8	CP	CP	CP	
Uncasville	Residence A	NA(CP)	NA(CP)	NA(CP)	
	Residence B	NA(CP)	NA(CP)	NA(CP)	
	Residence D	NA(FN)	NA(FN)	NA(FN)	Tetrachloroethylene
	Residence E	NA(CP)	NA(CP)	NA(CP)	

Key:
CP=Correct Positive; CN = Correct Negative
FP=False Positive; FN=False Negative
NA=Not applicable due to precluding factor--depth from foundation to groundwater contamination is less than 1.5 m.
WB=Wet Basement. This condition precludes the use of Figure 3 (for Q5) and the use of the Johnson and Ettinger Model.
Notes:
[1] Site data was compared to indoor air and groundwater screening values in Table 2.
[2] Site data was compared to indoor air and groundwater screening values in Table 3. The appropriate attentuation factor in this analysis was obtained from Figure 3.
[3] Site specific soil type, depth to groundwater, and building foundation type were used in the Johnson and Ettinger (J&E) model.
[4] When false positive or false negative outcomes resulted with both Q4 and Q5, the same compounds were responsible for the false outcome in each scenario.

Table F-5 (continued)
Summary Table
False Negative and False Positive Indoor Air Predictions Based on Comparison of Groundwater Concentrations to Target Levels, by Building at Each Site
$R=1x10^{-6}$

	Q4		Q5		J&E Site Specific	
	Number	**Percent**	**Number**	**Percent**	**Number**	**Percent**
Total CP and CN	34	100.0%	34	100.0%	34	100.0%
Total FP	0	0.0%	0	0.0%	0	0.0%
Total FN	0	0.0%	0	0.0%	0	0.0%
Total NA and WB	16	--	16	--	16	--
Total Number of Buildings	34		34		34	

Key:
CP=Correct Positive; CN = Correct Negative
FP=False Positive; FN=False Negative
NA=Not applicable due to precluding factor--depth from foundation to groundwater contamination is less than 1.5 m.
WB=Wet Basement. This condition precludes the use of Figure 3 (for Q5) and the use of the Johnson and Ettinger Model.
Notes:
[1] Site data was compared to indoor air and groundwater screening values in Table 2.
[2] Site data was compared to indoor air and groundwater screening values in Table 3. The appropriate attentuation factor in this analysis was obtained from Figure 3.
[3] Site specific soil type, depth to groundwater, and building foundation type were used in the Johnson and Ettinger (J&E) model.
[4] When false positive or false negative outcomes resulted with both Q4 and Q5, the same compounds were responsible for the false outcome in each scenario.

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Table F-6
Frequency of False Negative and False Positive Indoor Air Predictions Based on Comparison of Ground Water Concentrations to Target Levels, by Chemical[1]
Risk = $1x10^{-6}$

	Location	Benzene*			1,1- Dichloroethane			1,2-Dichloroethane*			1,1-Dichloroethylene			cis-1,2-Dichloroethylene [2]			trans-1,2-Dichloroethylene [2]		
		Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN
VI Q4 [3]	Alliant	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	--	--	--
	LAFB	--	--	--	13	0	0	13	0	13	13	0	0	13	0	0	13	0	0
	Uncasville	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Total	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**13**	**26**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**
VI Q5 [4]	Alliant	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	--	--	--
	LAFB	--	--	--	13	0	0	13	0	13	13	0	0	13	0	0	13	0	0
	Uncasville	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Total	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**13**	**26**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**
JE Site Specific [5]	Alliant	--	--	--	--	--	--	0	0	0	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	--	--	--
	LAFB	--	--	--	13	0	0	13	0	13	13	0	0	13	0	0	13	0	0
	Uncasville	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Hamilton-Sunstrand	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Total	**1**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**13**	**26**	**0**	**0**	**13**	**0**	**0**	**13**	**0**	**0**

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Table F-6 (continued)
Frequency of False Negative and False Positive Indoor Air Predictions Based on Comparison of Ground Water Concentrations to Target Levels, by Chemical [1]
Risk = $1x10^{-6}$

	Location	Ethylbenzene*			Tetrachloroethylene*			Toluene			1,1,1-Trichloroethane			1,1,2-Trichloroethane*			Trichloroethylene*			Vinyl chloride*			Xylene [2]		
		Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN	Samples	FP	FN
VI Q4 [3]	Alliant	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	--	--	--
	LAFB	--	--	--	13	--	13	--	--	--	13	0	0	13	0	1	13	0	0	9	0	1	--	--	--
	Uncasville	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	--	--	--
	Hamilton-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	1	--	--	--	1	0	0	--	--	--	--	--	--	0	0	0	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	0	0	--	--	--	--	--	--
	Total	1	0	1	13	0	13	1	0	0	13	0	0	13	0	1	33	0	0	9	0	1	1	0	0
VI Q5 [4]	Alliant	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	--	--	--
	LAFB	--	--	--	13	--	13	--	--	--	13	0	0	13	0	1	13	0	0	9	0	1	--	--	--
	Uncasville	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	--	--	--
	Hamilton-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	1	--	--	--	1	0	0	--	--	--	--	--	--	0	0	0	--	--	--	1	0	1
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	0	0	--	--	--	--	--	--
	Total	1	0	1	13	0	13	1	0	0	13	0	0	13	0	1	33	0	0	9	0	1	1	0	0
JE Site Specific [5]	Alliant	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	0	0	0	--	--	--
	Eau Claire	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	0	0	0	0	0	--	--	--
	LAFB	--	--	--	13	--	13	--	--	--	13	0	0	13	0	1	13	0	0	9	0	1	--	--	--
	Uncasville	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	0	0	0	--	--	--	--	--	--
	Hamilton-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	13	0	0	--	--	--	--	--	--
	MADEP	1	0	0	--	--	--	1	0	0	--	--	--	--	--	--	0	0	0	--	--	--	1	0	0
	Mountain View	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	7	0	0	--	--	--	--	--	--
	Total	1	0	0	13	0	13	1	0	0	13	0	0	13	0	1	33	0	0	9	0	1	1	0	0

Key:
FP=False Positive; FN=False Negative

Notes:
[1] For each chemical we indicate the total number of samples at each site for each chemical and the number of samples with False Positive or False Negative results at that site across all buildings. "--" means the chemical was not found at any building at that site.
[2] Toxicity values extrapolated from oral studies were used to develop screening levels for this chemical.
[3] Site data was compared to indoor air and ground water screening values in Table 2.
[4] Site data was compared to indoor air and ground water screening values in Table 3.
[5] Site specific soil type, depth to groundwater, and building foundation type were used in the J&E model.
* Ground water target concentration for this compound is based on the Maximum Contaminant Level (MCL) in drinking water.

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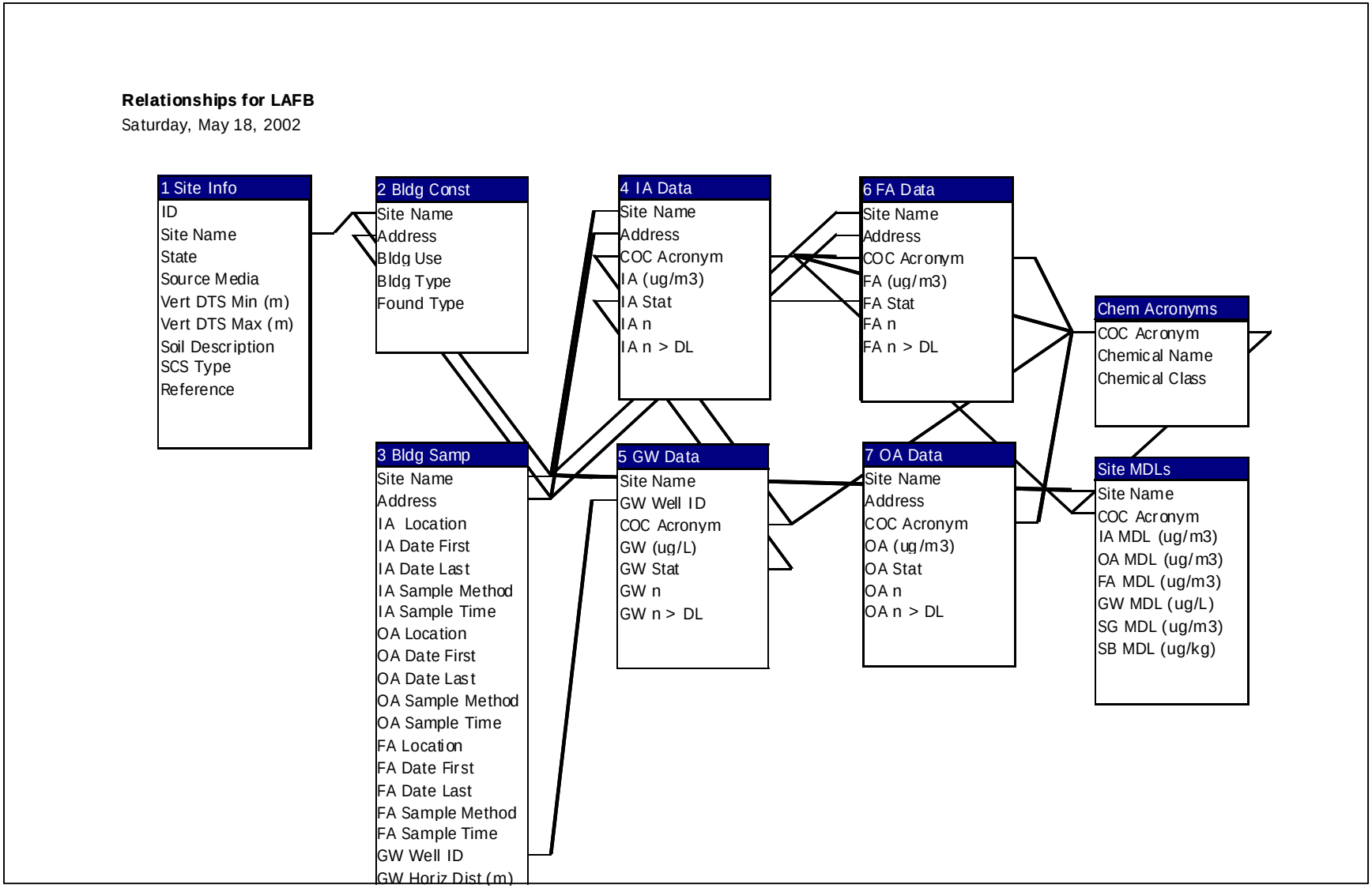
Figure F-1. Schematic Diagram of Empirical Database Structure and Element



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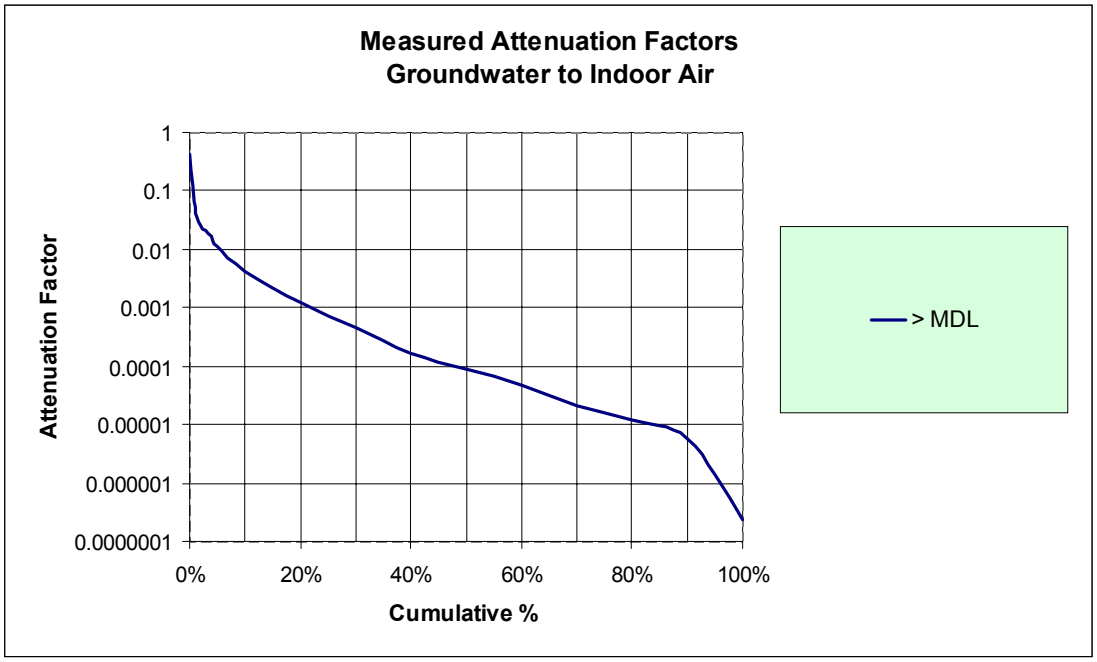

Figure F-2. Distribution of groundwater-to-indoor air attenuation factors for all residences in the empirical database with indoor air and groundwater measurements above their respective method detection limits (MDLs).

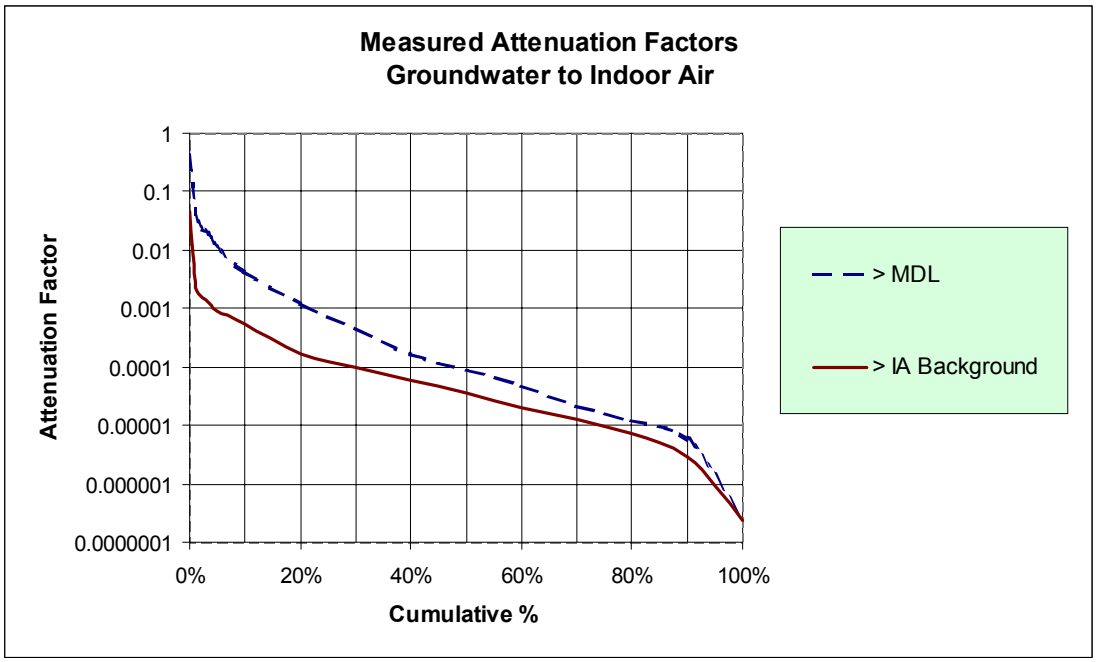

Figure F-3. Distribution of groundwater-to-indoor air attenuation factors for residences with concentrations above MDLs and above typical background levels.

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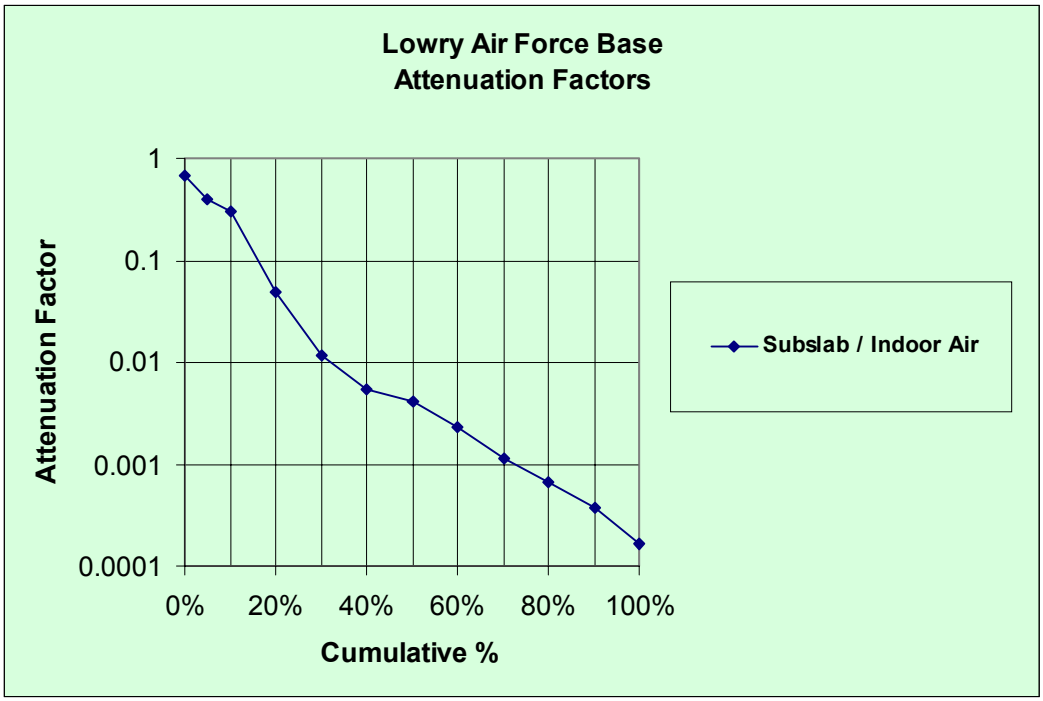

Figure F-4. Distribution of subslab-to-indoor air attenuation factors for residences for the subset of residences with indoor concentrations greater than the subslab concentrations measured below the residence's foundation. Subslab data were available for only one site—the Lowry Air Force Base in Colorado.

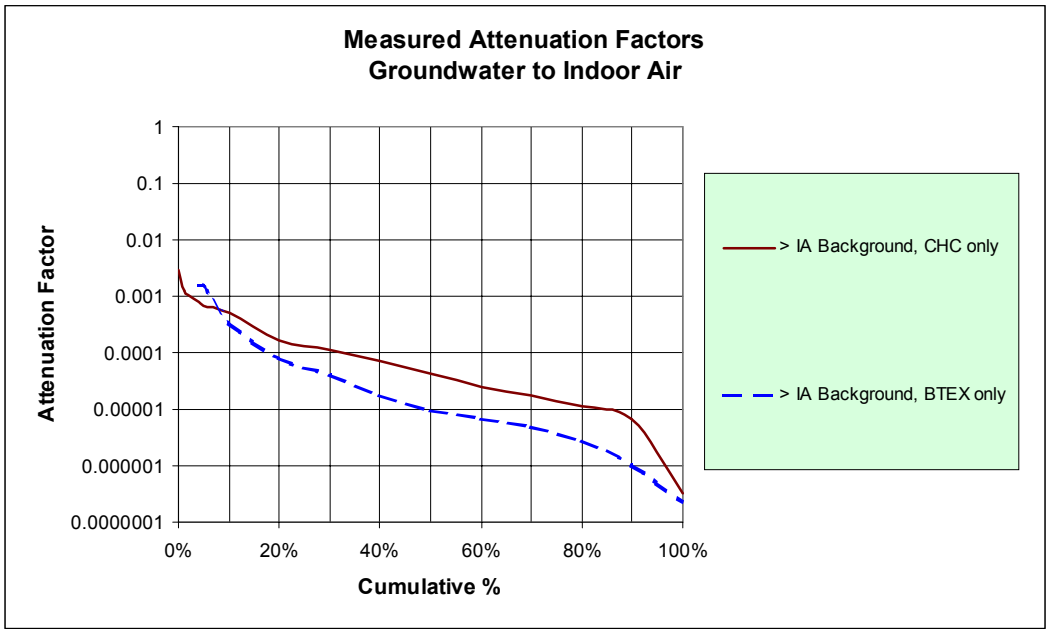

Figure F-5. Comparison of groundwater-to-indoor air attenuation factors for BTEX and chlorinated hydrocarbons (CHC).